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BOTANICAL PHENOMENA AND THE PROBLEM OF RECENT COASTAL SUBSIDENCE[1]

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(WITH NINE FIGURES)

Fifty-five years ago GEORGE H. COOK[2] published his important paper on the subsidence of the land along the coasts of New Jersey and Long Island, in which he cited much evidence to prove that these coasts were gradually sinking at a rate of more than half a meter per century. Before this time a number of writers had called attention to certain phenomena which seemed to them to indicate a progressive subsidence of the coast; and since the publication of COOK's article, many reports upon this interesting subject have appeared. A few of these authors have argued in favor of the recent elevation of certain parts of the coast; a few others have maintained that the evidence of recent changes of level were not convincing; but by far the greater number have supported the theory of recent subsidence, and have described indications of a sinking of the land for almost all parts of the coast between Prince Edward Island and Florida. It is today generally accepted as a well established fact that the Atlantic coast of North America is gradually subsiding, at a rate which is variously estimated from 20 to 75 cm. per century.

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[1] The substance of a portion of this paper formed part of an article published in the Annales de Géographie, May 1912, under the title "Fixité de la côte Atlantique de l'Amérique du Nord."

[2] COOK, G. H., On a subsidence of the land on the seacoast of New Jersey and Long Island. Amer. Jour. Sci. II. 24:341-354. 1857.

The supposed changes of level of the Atlantic coast have interested me for several years. A study of the form of Nantasket Beach, near Boston, showed that this portion of the coast could not have subsided more than a meter during the last 1000 or 2000 years.[3] An examination of certain shore line changes produced at Scituate, also near Boston, by the great storm of 1898, showed that all the appearances of a subsidence of the coast could be produced by an increased height of high tide resulting from a change in the form of the shore line.[4] Finally, aided by a grant from the Shaler Memorial Fund of Harvard University, by the excellent services of my three assistants, Messrs. D. C. BARTON, J. K. WRIGHT, and G. B. REED, and by the cordial cooperation of a large number of geologists, engineers, and officials of state and national surveys, I have been able to study the most important localities on the Atlantic coast from the northern side of Prince Edward Island to the Florida Keys, as well as a number of places on the coasts of Sweden, England, and Holland. The results of these studies seem to me to justify, for the Atlantic coast of North America, the following conclusions: (1) There can have been no long-continued progressive subsidence of this coast at a rate of 20 cm. or more per century, during the last few thousand years. The coast has remained at least comparatively stable throughout this period. (2) The coast cannot have subsided as much as 30 cm. in the last century. (3) There is no satisfactory evidence of any subsidence whatever during the last few thousand years.

In the present paper no attempt is made to consider all phases of the interesting problem of recent coastal subsidence; attention is here directed exclusively to the consideration of some of the botanical phenomena supposed to prove such a subsidence. If apology is needed for my venturing to discuss botanical phases of the question, and in a botanical journal, my plea is that I am a firm believer in what has been aptly termed cross-fertilization of the sciences. The study of a complex problem has forced me to

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[3] JOHNSON, D. W., and REED, W. G., The form of Nantasket Beach. Jour. Geol. **18**:162–189. 1910.

[4] JOHNSON, D. W., The supposed recent subsidence of the Massachusetts and New Jersey coasts. Science N.S. **32**:721–723. 1910; also The botanical evidence of coastal subsidence. Science N.S. **33**:300–302. 1911.

investigate botanical phases of the question, and my modest excursions into the realms of a sister science have been made most profitable because of the courtesy and generous assistance of some of my botanical colleagues. I shall be glad if the observations here set down prove of interest to some of the many students of botany who have noted the indications of changes of level afforded by plant life along the coast.

Throughout this article the expression "recent subsidence" is employed to designate subsidence within the last few thousand years, and "remote subsidence" to designate a sinking of the land which occurred more than 4000 or 5000 years ago. One may divide the botanical evidences of recent subsidence of our Atlantic coast into three classes, according as they are (1) wholly fictitious appearance of changes of level; (2) phenomena produced by local changes in tidal heights without any real change in the general level of either land or sea; and (3) phenomena really produced by a sinking of the land, but produced so long ago that they cannot properly be cited as proofs of a subsidence within the last few thousand years. Let us first consider those supposed proofs of recent subsidence which are based on

1. Fictitious appearance of changes of level

STANDING FORESTS KILLED BY THE INVASION OF THE SEA

At many points on the Atlantic coast one may observe large numbers of trees killed by salt water so recently that they still stand erect, and even retain their branches. These trees have often been cited as a convincing proof of the recent progressive subsidence of the land. Among the localities where standing forests killed by the sea have been supposed to show with special clearness a recent subsidence of the land, I will mention but a few. GANONG[5] in one of his series of "Notes on the natural history and physiography of New Brunswick," speaking of the low shores of South River, near Pokemouche, says, "in places the dead forest trees still standing with their roots immersed by the highest tides,

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[5] GANONG, W. F., On the physiographic characteristics of the Pokemouche and St. Simon rivers. Bull. Nat. Hist. Soc. New Brunswick 5:524–526. 1906.

afford striking evidence of the rapid subsidence this coast is undergoing." ABRAHAM GESNER[6] described standing forests of beech, birch, and maple, killed by the seawater which overflowed their roots, as a proof that the coasts of Cascumpeque Harbor in Prince Edward Island had undergone the most recent subsidence of which he had knowledge. COOK, in the paper referred to in the first paragraph of this article, describes dead forests still standing, found on several parts of the New Jersey coast. Sir CHARLES LYELL[7] saw in standing forest trees killed by the tide near the mouth of Cooper River, South Carolina, a proof of very modern subsidence of that coast.

The region described by GANONG has been examined by GOLDTHWAIT, with whom I have had the privilege of cooperating in the work along the coast of southeastern Canada. After a careful study of the dead trees on this part of the coast, GOLDTHWAIT[8] has reached the conclusion that death has resulted in some cases from fire, and in others from a local rise in the high tide level after the manner indicated in section 2 below. I have myself made a careful study of the Cascumpeque Harbor locality and find that the dead trees described by GESNER may be reasonably explained without imagining a subsidence of the coast.[9] Three distinct causes have operated to kill the forest of this portion of the shore. On the outer side of the barrier beach the waves are cutting away the shore and hurling the sands up into the forest. During storms the waves break over the sandy accumulation, and the salt water saturates the sand about the roots of the trees and is ponded back in the low depressions, remaining long enough to kill the trees. Forests killed in a similar manner are found on parts of the North Carolina capes. Inside Cascumpeque Harbor the small waves of the bay have gently sapped the mainland shores, removing the

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[6] GESNER, ABRAHAM, On elevations and depressions of the earth in North America. Quar. Jour. Geol. Soc. London 17:381–388. 1861.

[7] LYELL, CHARLES, Travels in North America. London. 1845. 1:174–175.

[8] GOLDTHWAIT, J. W., Supposed evidences of subsidence of the coast of New Brunswick within modern times. Unpublished manuscript to appear in an early issue of the Victoria Museum Bulletin.

[9] JOHNSON, D. W., The shore line of Cascumpeque Harbor, Prince Edward Island. Geog. Jour. London 42:152–164. 1913.

earth from about the roots of the trees along the low coast and thus exposing them to salt water. The barrier beach which separates the bay from the ocean is interrupted by several tidal inlets; and a variation in the number and width of these inlets has permitted a local rise in the high tide surface with a consequent invasion of the forest by the salt water (see section 2 below). The dead forests along the coasts of New Jersey, the Carolinas, and Georgia, many of which I have examined, are most frequently to be explained as the result of such local fluctuations of high tide level. I have seen no case where the killing of the trees could safely be ascribed to a sinking of the coast. On the contrary, the localization of the dead trees at those points on the coast most favorable to the operation of the local causes mentioned above, and certain others described later, is sufficient evidence that their death is not the result of a general subsidence of the land.

FIG. 1.—Live trees in Albemarle Sound, giving fictitious appearance of coastal subsidence.

As a variant of the above type of evidence, one may class the occurrence of live trees standing in deep water at the heads of sounds and bays, where the water is too fresh to readily kill trees which have reached maturity. It is evident that these trees could not have commenced to grow in water 5 or 10 feet deep, and it was therefore with especial interest that I learned from Dr. C. A. DAVIS that great numbers of such trees occurred near the headward portion of Albemarle Sound, especially in the vicinity of Elizabeth City, North Carolina, affording, in his opinion, exceptionally good proof of recent coastal subsidence. On visiting the locality I found hundreds of live cypresses standing in water which was often over 5 feet in depth; but the spreading base of these trees was just above water level at the same elevation as on the adjacent low shore (fig. 1); while the underwater parts divided into spreading roots between which an oar could be readily passed. It was quite evident that the trees had grown, like their neighbors, on a low coast composed of peaty soil; and that the washing away of the soil by waves had left the trees standing out in the water. This interpretation was confirmed by the finding of occasional islets of peat about some of the isolated trees. There was no indication of any change in the relative level of land and sea.

SUBMERGED STUMPS

Closely allied to the foregoing botanical evidence of subsidence is that furnished by submerged stumps. These are found along all parts of the Atlantic coast, at depths varying from a few inches below high tide to ten feet or more below low tide level, and have been repeatedly cited by both botanists and geologists as conclusive proofs of recent subsidence. It is hardly necessary to cite specific descriptions of these submerged stumps, as they are such common features along our shores.

A study of the submerged stumps convinces one that there is a great variety of ways in which they may be produced independently of coastal subsidence. Along the low shores of South Carolina and Georgia the small waves formed in the passage between the "Sea Islands" continually undermine trees and let them down into the salt water. So gently does the process operate that the trees often remain erect; and I have seen all stages from trees still living on the edge of the shore 0.5–1 meter above tide, through others whose broad spreading roots were half undermined, thus allowing the trees to incline forward and sink toward the lower level, to still others which had been wholly undermined and had tipped back to a nearly vertical position, standing erect but dead in the salt water. These trees later break off at the water line and give upright submerged stumps. The fact that dead trees and submerged stumps are often produced in this manner was clearly recognized by TUOMEY[10] in his interesting report on the geology of South Carolina. This same author[11] likewise emphasized the fact that many so-called submerged stumps are merely tap roots of certain trees which descend to a great depth. The loblolly pine has a tap root as large as its trunk which runs down 2 or 3 meters, and then sends off smaller roots. A forest of such trees growing on a low coast may be attacked by the waves, and as the earth is removed the trees die and finally break off at or below water level. In this way deeply submerged "stumps" are produced which will seem to the ordinary observer a convincing proof of subsidence.[12] Fig. 2 is a diagrammatic representation of several stages in this process, which we found particularly well shown in the "Sea Islands" of Georgia.

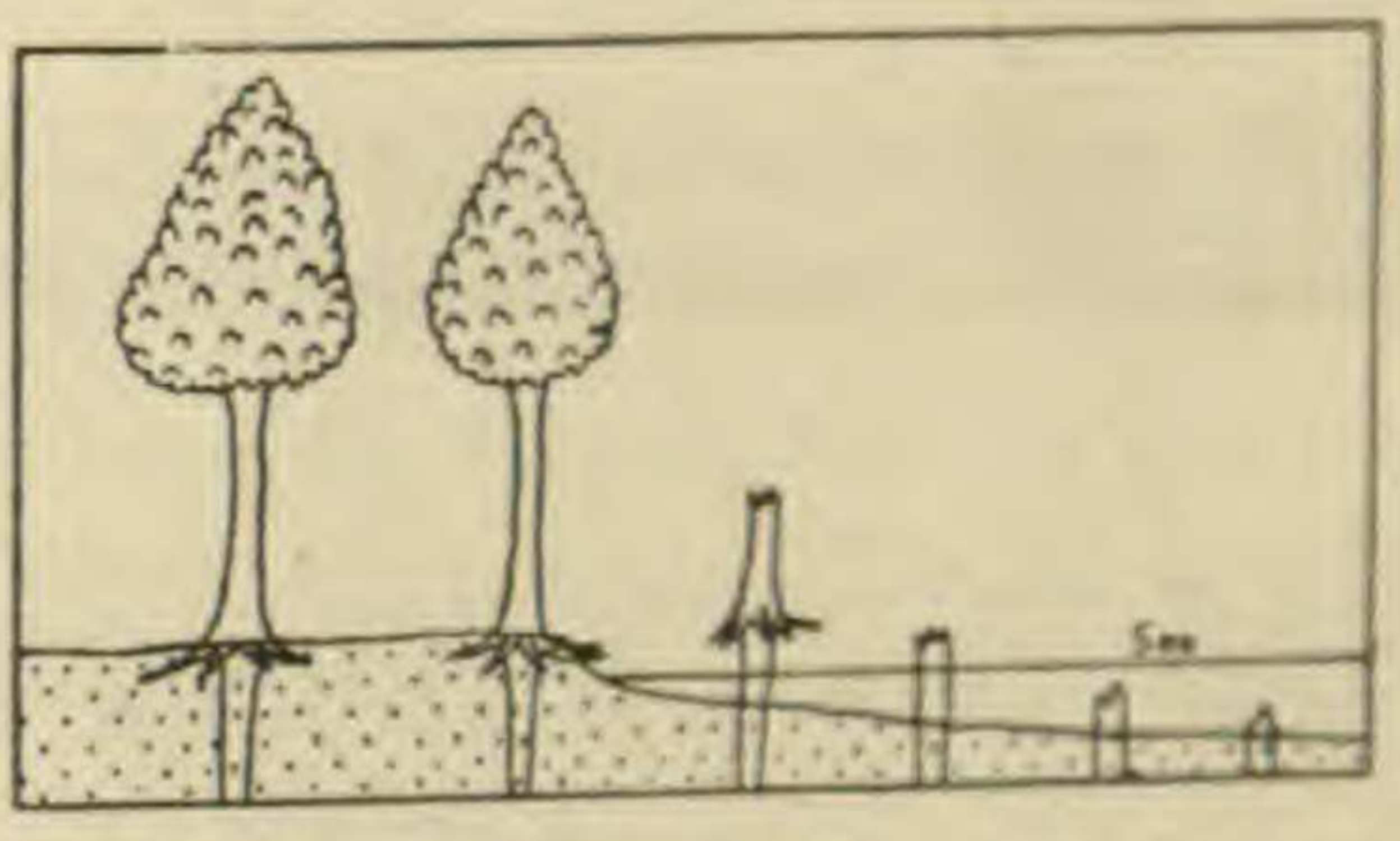

FIG. 2.—Submerged stumps resulting from normal retrogression of the shore line.

Where the sea is cutting into the "Black Bank," a peat bog near Cascumpeque Harbor, many stumps had been washed out of the bog, transported by waves and currents some little distance, and left stranded, often in an upright position, on the beach and in the shallow water of the bay. Submerged stumps, due to a local rise of the high tide level, to the compression of peat bogs caused by a lowering of the ground-water level as the waves cut into the shoreward side of such bogs (fig. 3), to the compression of peat

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[10] TUOMEY, M., Report on the geology of South Carolina. Columbia. 1848. p. 194.

[11] *Op. cit.*, 195.

[12] LYELL. CHARLES, A second visit to the U.S. of North America. 2d ed. London. 1850. 1:316–317.

deposits under the weight of barrier beaches (fig. 4), and to other causes, have been observed at many points along the coast. The more one sees of this type of evidence the more does he realize its unreliability.

SUBMERGED PEAT

Another botanical evidence of subsidence, frequently appealed to with confidence by those who believe in recent subsidence of the Atlantic coast, is the submerged peat exposed at many points along the shores, sometimes a little below high tide, often a considerable distance below low tide. Such deposits may consist of the remains of fresh water vegetation, or of the remains of marine plants; and both types of deposits have been cited as proofs of a recent sinking of the coast. The fresh peat is frequently overlaid by salt peat; sometimes the reverse is the case; while in other places one or the other type of peat occurs alone. It is uncommon, however, to find such a repeated interstratification of fresh peat with marine deposits as SKERTCHLEY[13] has described for the English fenland, or CAYEUX[14] for a portion of the French coast, although

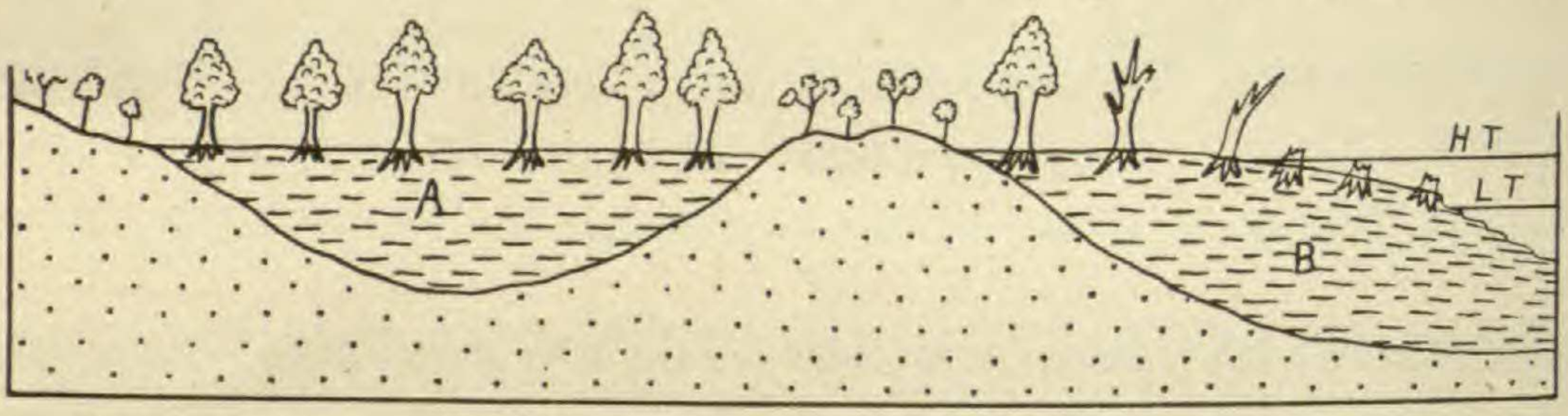

FIG. 3.—Submerged peat and stumps produced by an invasion of peat bogs by the sea; *HT*, high tide; *LT*, low tide.

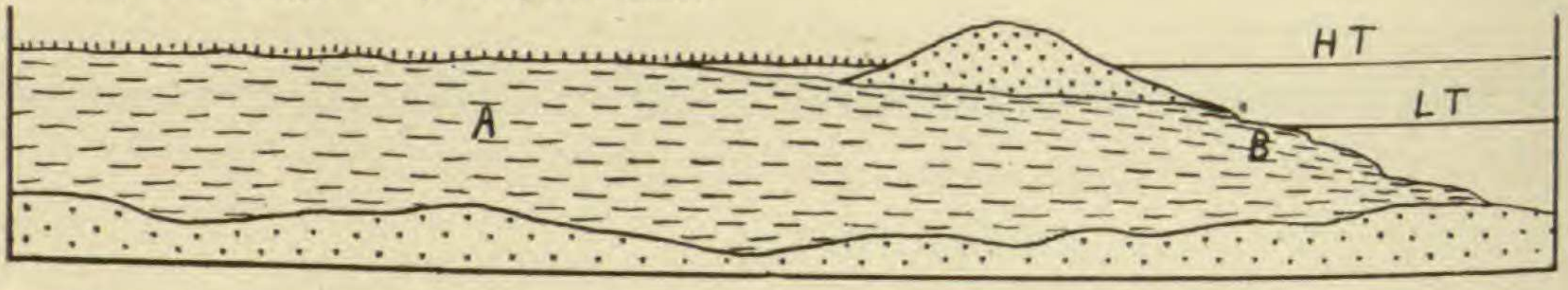

FIG. 4.—Submerged peat outcropping at low tide (*B*) compressed by weight of barrier beach, which is encroaching on salt marsh peat deposit (*A*); *HT*, high tide; *LT*, low tide.

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[13] SKERTCHLEY, S. B. J., The geology of the fenland. Memoir Geol. Surv. England and Wales. London. 1877. pp. 145–151, 172–174.

[14] CAYEUX, L., Les tourbes immergées de la côte Bretonne dans le région de Plougasno-Primel (Finistère). Bull. Soc. Géol. France IV. **6**:142–147. 1906.

essentially the same conditions developed on a small scale are occasionally encountered on our coast.

Evidently the fresh peat cannot have formed in its present position, exposed to marine action. Indeed, it has been argued that such peat containing upright stumps cannot form in depressions below high tide level back from the shore line because the level of the ground-water would cause such depressions to contain ponds of water in which trees would not grow. Hence it is concluded that submerged fresh peat is a proof of recent coastal subsidence. This conclusion seems to me open to criticism on several grounds. In the first place, "floating bogs" formed of sphagnum and carrying trees of considerable size upon them sometimes cover the surfaces of ponds. The sinking of such a bog, as the trees increase in size or as new material is added to its upper surface, would carry upright stumps down below sea-level. Decomposition of bogs to produce such a semi-liquid mass as is often found under their surfaces might permit stumps to sink slowly to the bottom and remain upright there. The possibility of some such history for a peat bog encroached upon by the sea must be definitely excluded by those who would employ these bogs as a proof of coastal subsidence. In the second place, it should be noted that the lower portions of such bogs may be of very great antiquity; even if they formed above sea-level and were carried downward by subsidence of the coast, this event may have taken place many thousands of years ago. Hence such submerged bogs should not be offered as a proof of recent subsidence (within the last 2000 or 3000 years), as has so often been done. In the third place, when such a bog is encroached upon by the sea, the level of the ground-water table in the bog, formerly at or near its surface, is rapidly lowered. Near the seaward margin of the bog the ground-water table may decline to mean sea-level; and, right at the margin, to low tide level when the tide is out. As a result of this removal of water, the surface of the bog is rapidly lowered, carrying down with it trees which are killed by exposure to high tide (fig. 3). How extensive such a settling of the surface may be, is suggested by fig. 5, which represents the result of an artificial lowering of the ground-water level. Furthermore, the alternate submergence and draining of the bog removes so much of its content that the surface may even slope down to a level considerably below that of low tide. Submerged deposits of fresh peat containing upright stumps, therefore, are not to be regarded as a conclusive proof of subsidence, either remote or recent.

The salt marshes of a portion of our coast are underlaid by peat, often remarkably pure and reaching a depth of 6 meters or more, composed largely of the roots of *Spartina patens* and other salt marsh grasses which grow only near the high tide level. In 1862 MUDGE[15] called attention to this structure of the salt marshes along the New England coast, and showed that the deeply buried portions of the peat must have formed at high tide level. Their present position he attributed to an undermining of the subsoil by fresh water, known by borings to descend from the upland and to pass through the sand found below a clay bed under the marsh

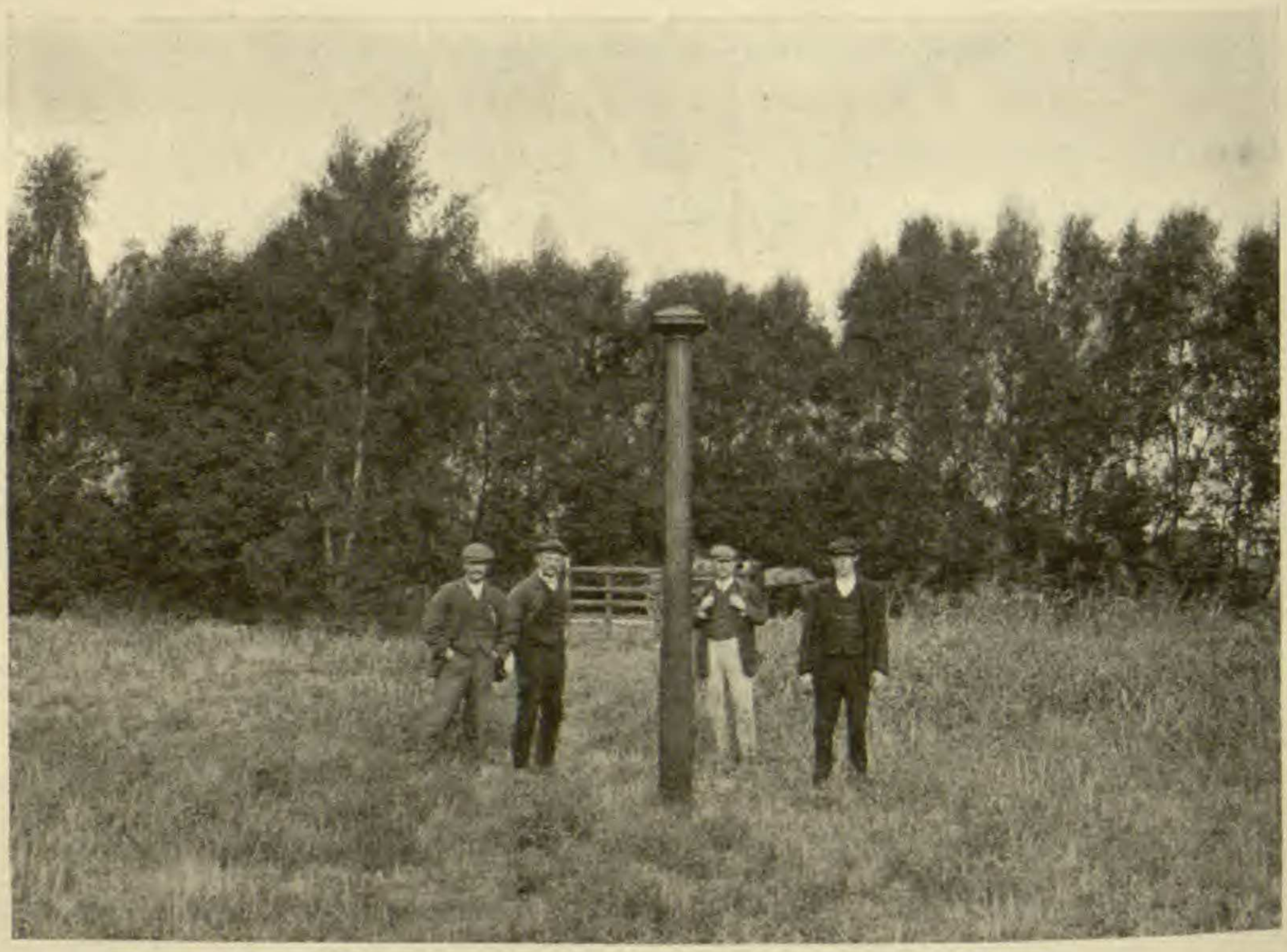

FIG. 5.—Settling of peaty land due to artificial lowering of ground-water level in the fenland of England; in 1848 the surface of the land was even with the top of the post.

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[15] MUDGE, B. F., The salt marsh formations of Lynn. Essex Inst. Proc. 2:117–119. 1862.

near Boston; an explanation which seems hardly competent to account for such a widespread phenomenon. More recently DAVIS[16] of the United States Bureau of Mines, an expert in the examination of peat deposits, has placed especial emphasis upon that feature of salt marshes described by MUDGE, and believes that he has found therein a conclusive proof of a gradual subsidence of the Atlantic coast, probably not faster than a foot a century, continuing up to the present time. Others have likewise thought that they found in submerged salt peat a proof of recent subsidence, and have cited the outcropping of such peat at low tide on the seaward side of barrier beaches, bearing the impressions of the hoofs of cattle and horses and of wagon wheels, as certain proofs of very recent marked subsidence.

It is well known that the attack of the waves often drives a barrier beach inward over the salt marsh. The enormous weight of the beach necessarily results in a compression of the peat deposit, so that the surface of the latter is exposed near or below low tide level on the seaward side of the beach (fig. 4). On the coast near Boston a barrier beach has been driven back over a salt marsh more than 70 meters in twelve years. Today the former surface of the meadow, with the wheel tracks of an old road, impressions of horses hoofs, and the stumps of trees which had gained a foothold on the marsh inside of the beach, are all exposed at low tide on the seaward side of the beach. Those who would interpret this as a result of coastal subsidence must admit a subsidence of perhaps two meters in twelve years, of which there is no corroborating evidence whatever. In fact, the bending down of the former surface of the marsh is readily apparent where the peat outcrops toward the sea; and the fact of extensive compression is shown by two sections taken through the peat deposit; one in the marsh a short distance back of the beach, revealing about four meters of relatively soft peat; the other near low tide level, showing but one meter of very dense, compact, tough peat. The seaward slope of the former marsh surface may be obscured back of the beach by more recent deposits built up to high tide level (fig. 4).

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[16] BASTIN, E. S., and DAVIS, C. A., Peat deposits of Maine. Bull. 376, U.S. Geol. Surv. 19–21. 1909; also DAVIS, C. A., Salt marsh formation near Boston, and its geological significance. Economic Geology 5:625. 1910.

In sections 2 and 3 below we will inquire further into the reliability of salt peat below sea-level as a proof of recent subsidence.

2. Phenomena produced by a local rise in the high tide level

It has seemed necessary to treat the fictitious appearances of changes of level as fully as has been done above, because of the widespread belief in the value of such phenomena as proofs of coastal subsidence. The local fluctuations of high tide level, now to be discussed, are of much greater importance, but may be explained in a shorter space. The principle of these fluctuations will be readily apparent from figs. 6–8.

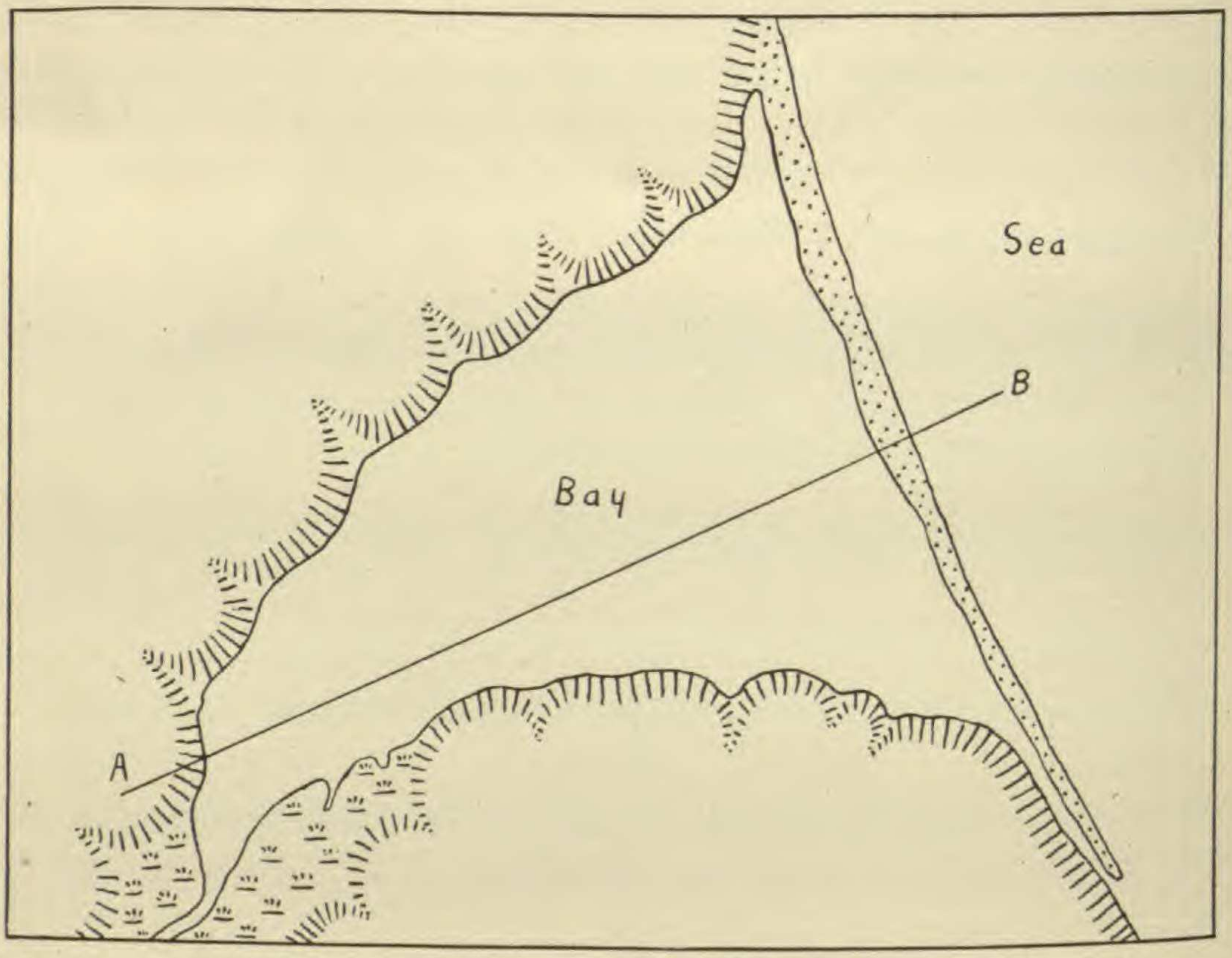

FIG. 6.—Bay separated from the open sea by a barrier beach

On a tidal coast, if we have a bay like that shown in fig. 6, almost separated from the open sea by a barrier beach, but connected with it by a narrow tidal inlet, the waters of the rising tide in the sea will pass through the tidal inlet with so much difficulty that the surface of the bay will rise much more slowly than the surface of the sea. When the tide in the sea has reached its maximum, and has begun to fall, the surface of the bay will still remain much lower. When it is low tide in the sea, the water in the bay will remain at a higher level, because this water cannot escape fast enough to maintain equality of levels between the two water bodies. Hence, high tide level in the bay is lower than high tide level in the sea. This is shown in fig. 7, which represents a cross-section of such a bay as fig. 6 in the direction *AB*. It is evident that around the shores of the bay, trees and other fresh water vegetation will grow down to the level of the high tide of the bay, and thus *below* the high tide level of the adjacent sea. Salt marshes in the bays will likewise grow up to the high tide level of the bay, farmers will build dikes to reclaim their marshes at this same level, and in other ways the level will be so marked as to render readily perceptible any increase in the height of the tides.

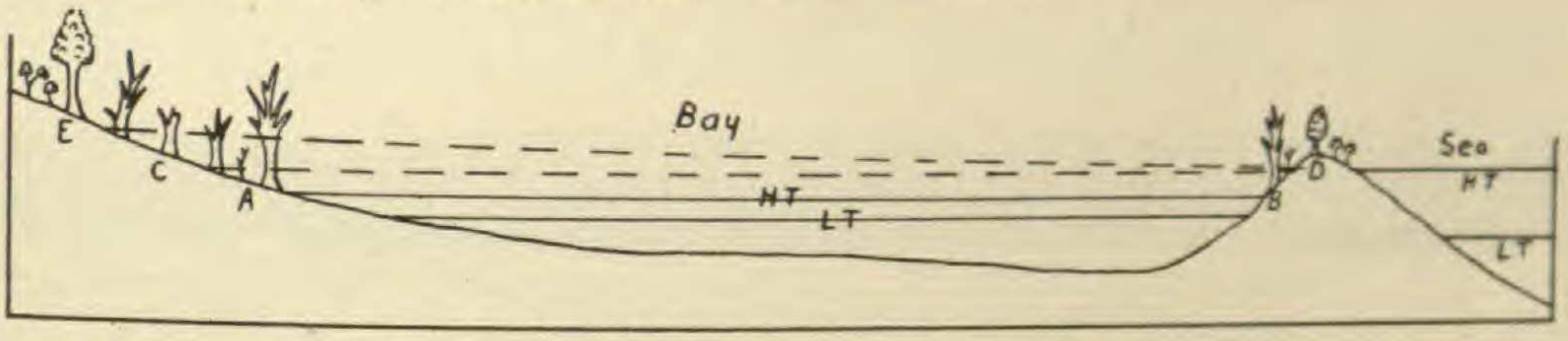

FIG. 7.—Diagram showing fictitious subsidence of the coast; as long as the barrier beach (*D*) nearly closes the mouth of the bay, high tide (*HT*) in the bay is lower than high tide in the open sea; trees grow down to this lower level (*AB*) along the shores of the bay; when the barrier beach is broken through or removed, high tide in the bay rises as high (*CD*) as the open sea, and all the trees between the levels *AB* and *CD* are killed by the salt water; if the bay narrows going inland, the tide is forced to rise even above the level it attains in the open sea, or to the position *ED*, and at the head of the bay all the trees between *A* and *E* are killed; in addition to these submerged forests, other fictitious indications of subsidence are thus produced.

Now let us consider the consequences which must follow if storm waves make a large breach in the barrier beach. With free access to the bay through the larger opening, the tidal waters will at once rise as high in the bay as in the open sea (*CD*, fig. 7). All trees whose bases are below the line *CD* will be washed by the tides and killed. The standing forests of dead trees will later be represented by submerged stumps. Dikes raised by the farmers will be overflowed by the tides. The surface of the salt marsh will build up to the new high tide level, enveloping both stumps and dikes. Fresh water peat, formerly beyond the reach of salt water, may now be buried under a layer of salt peat. In short, most of the phenomena usually cited as proofs of general coastal subsidence will be produced by a local rise of the high tide caused by change in the form of the shore line. If the bay narrows inland as shown in fig. 6, the tidal wave will increase in height as it advances, so that the level of high tide at the head of the bay will rise far above that of the open sea (*ED*, fig. 7). In this case all the trees between *A* and *E* will be killed at the head of the bay, and the appearance of subsidence will be unusually pronounced.

Fig. 8 represents the consequences of the opposite type of change. When the bay was open to the sea, the waves cut a cliff (*C*) and bench (*B*). But the construction of a barrier beach (*D*) has so

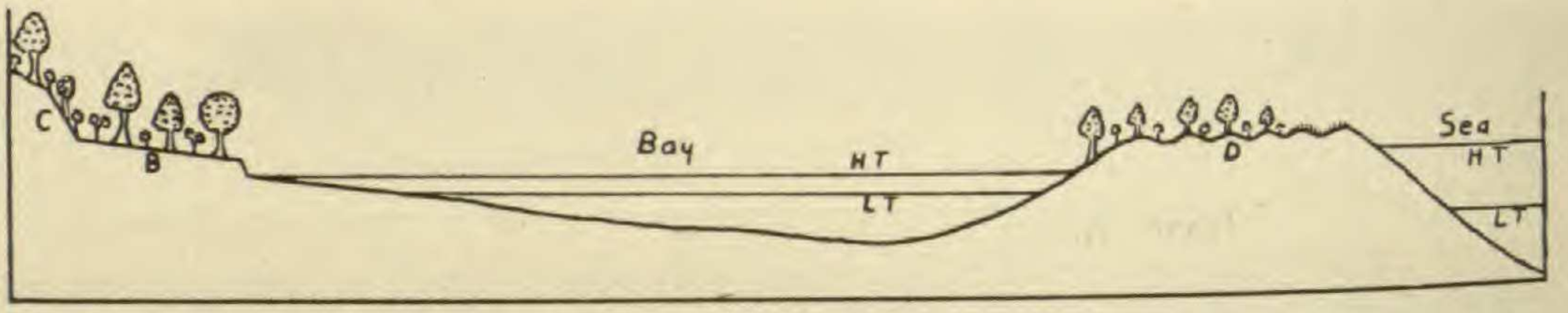

FIG. 8.—Diagram showing fictitious elevation of the coast; before the barrier beach (*D*) was constructed, the tide in the bay rose as high as in the open sea, and the cliff (*C*) and bench (*B*) were carved by the waves; since the building of the barrier beach, high tide (*HT*) in the bay is lower than in the ocean, the cliff and bench are no longer reached by the waves, and appear to represent an "elevated shore line"; the uniform altitude of the beach ridges on the barrier beach shows that the relative level of land and sea have long remained constant.

reduced the level of high tide in the bay that the waves no longer reach the cliff or the inner part of the bench. These become covered with trees and other fresh vegetation, and constitute what is usually called an "elevated shore line." Cliffs and benches of this origin have been cited as proofs of recent coastal elevation.

In applying the above principle to the interpretation of supposed elevations and subsidence of the land, the following points should be kept in mind:

a) If, instead of a sudden rupture of the barrier beach, we have a gradual enlargement of the inlet, the shores of the bay will appear to undergo slow and progressive subsidence. The gradual closing of an inlet, or the progressive shifting of its position, will likewise cause the appearance of slow changes of level. Such changes are more common, but less striking, than those which are more sudden.

b) The total apparent subsidence produced in this manner may considerably exceed one-half of the tidal range in the adjacent sea. A considerable thickness of high tide salt peat may thus be produced without coastal subsidence.

c) Half-tide level does not necessarily remain the same after the change in high tide level.

d) The application of the principle here set forth is not restricted to bays of the type shown in fig. 6. Vast lagoons parallel to the coast, such as those of Long Island and New Jersey; open bays whose mouths are being widened by wave erosion; salt marshes traversed by meandering tidal channels; the intricate network of passes between the low and changeable islands of South Carolina and Georgia, or parts of the Holland coast; all these present favorable conditions for local changes of tide level consequent upon changes in the width, length, or depth of the tidal channels.

e) Many bays now open to the sea were once doubtless more or less nearly closed by barrier beaches. This is especially true along glaciated shores where the waves and currents have effected in post-glacial time, and are still effecting, comparatively rapid changes in the form of the shore line.

f) Appearances of subsidence predominate over those of elevation because marsh deposits tend to sink to the new level when high tide level is lowered; because the immediate destruction of fresh water vegetation by salt water when the high tide limit is raised is more striking than the slow recovery of marine area by fresh vegetation when the high tide level is lowered; and because in the cycle of shore line development retrograding exceeds prograding, and retrograding tends to carry higher tide levels into low lands where apparent changes of level are most easily recognized.

In order to determine how far conditions along the Atlantic coast were favorable to such future changes in high tide level as would produce apparent coastal subsidence, we made careful comparison of the height of the same high tide in partially closed bays, in lagoons, and in tidal creeks of salt marshes on the one hand, and in the ocean on the other hand, at a large number of points along the coast from New Hampshire to Florida. The results of these surveys show that such favorable conditions occur abundantly along the entire coast. Differences of level in the high tide of the two contrasted water bodies amounting to nearly a meter were found, and from other surveys farther north it is known that still greater differences occur.

That such local changes of high tide level have occurred in the past is equally evident. At Scituate near Boston, the storm of 1898 made a large opening in a barrier beach which formerly nearly closed the mouth of a small bay. The high tide level immediately rose, according to the inhabitants, more than half a meter, and extensive areas of growing trees were invaded by salt water, the trees now standing erect but dead (fig. 9). Dikes built to reclaim portions of the former marsh surface are overflowed by the tides, and the marsh is building up to the new level.

FIG. 9.—Trees killed by local rise of high tide, near Scituate, Mass., giving fictitious appearance of coastal subsidence.

In 1811 a break in a barrier beach a short distance to the south is said to have resulted in the death of many trees, the stumps of which have recently been extracted from the shallow shoreward portion of the marsh. At Cascumpeque Harbor, Prince Edward

Island, there have been several recent changes in the number and position of the tidal inlets connecting with the sea, and the inhabitants date the death of certain of their trees to a new inlet opened some years ago. Along the New Jersey coast the general surface of the marsh slopes downward toward the land, and on the Delaware Bay section of this shore the waves are cutting rapidly into the marsh, which is unprotected by barrier beaches. As a result of the consequent shortening of the meandering tidal creeks, the tides rise progressively higher and higher toward the heads of the creeks; the salt marsh builds gradually up to the new level of high tide, encroaching on the upland, killing the trees, and producing other evidence of progressive subsidence of the land. In the sea islands of South Carolina and Georgia we observed a number of more or less restricted localities where forests had been killed by a rise of high tide level following changes in size and position of tidal channels and bars, and one place where the death of the trees is dated from the cutting of a canal between two tidal channels. On the other hand, appearances of elevation of the land caused by a local lowering of the high tide level are not lacking. "Elevated" cliffs and benches of this origin were observed at a number of points on the coasts of Massachusetts, New Jersey, North Carolina, and Florida.

3. Phenomena due to remote subsidence

Frequent warnings have been uttered, most ably by Suess, against the danger of confusing evidences of ancient changes of level with evidences of recent changes of level. Yet this error is found all too often in writings on this subject even today. Stumps deeply buried in the salt marshes are correlated with the invasion of cultivated fields by the tides; deeply buried salt peat is correlated with the dying of forests along the shore today; and on the basis of such correlations it is argued that we are in the presence of a great movement of subsidence which has continued uninterruptedly throughout recent time. It has even been argued that the embayed or drowned river valleys of the Atlantic coast are a conclusive proof of recent subsidence.

It is of the highest importance to recognize the possibility that deeply submerged stumps and peat, embayed valleys, and similar evidence may have been produced by a downward movement of the land which entirely ceased thousands of years ago; and that they may be wholly unrelated to those evidences which may properly be designated as recent. Attacking the problem from this point of view, I have been unable to find a single evidence of recent change of level on the Atlantic coast which may not be reasonably explained either as a fictitious appearance of changes of level, or as the result of a local fluctuation in the level of high tide. On the other hand, I have been unable to find a single conclusive proof of a change of level which is not in all probability of considerable antiquity.

The best example of deeply submerged stumps which I have seen on the entire coast is that so well described by DAWSON[17] at the head of the Bay of Fundy. The position of these stumps indicates a veritable subsidence of the land, but they have been buried under the great thickness of silt since the embayment of the region, and have been brought to light again in recent time by a shifting of a tidal channel. The position of the more deeply buried portions of the salt peat under the salt marshes is most reasonably explained as the result of coastal subsidence; but this peat may well be of considerable antiquity and probably dates well back toward the early part of post-glacial time at least.

In closing this account of the relation of botanical phenomena to the problem of recent coastal subsidence, I desire to call attention to the application of some of the above considered principles to certain evidence lately presented by BARTLETT.[18] According to this author, a peat bog at Quamquisset Harbor, near Woods Hole, occupies a kettle hole and represents successive layers of vegetation continuously built up to the surface of a ground-water table which rose higher and higher as the land subsided. This subsidence required something over 2000 years, and is still in progress, the sea having recently cut into the bog deposit.

Irrespective of the question as to whether the Woods Hole

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[17] DAWSON, J. W., On a modern submerged forest at Fort Lawrence, Nova Scotia. Quar. Jour. Geol. Soc. London 11:119–122. 1855.

[18] BARTLETT, H. H., The submarine *Chamaecyparis* bog at Woods Hole, Massachusetts. Rhodora 11:221–235. 1909; also Botanical evidence of coastal subsidence. Science N.S. 33:29–31. 1911.

bog affords "incontrovertible evidence" of recent subsidence, as BARTLETT believes, that author is to be congratulated on having set forth in a clear manner the series of changes which will occur in a bog occupying a depression closed from the sea, on a coast which is really subsiding. But the particular case to which BARTLETT applies this principle seems to me unfortunate. In the first place, one must question whether the depression in which the bog deposit occurs is really a kettle hole. There are, to be sure, many kettle holes in the terminal moraine of this region; but the Quamquisset Harbor bog near Woods Hole appears to occupy a normal stream channel in drift which is probably older than the moraine, the channel having been somewhat modified by later ice action. Like many other similar channels which I have studied, this one was probably open to the sea, in which case the entire history of the bog must have been quite different from that imagined by BARTLETT.

Even if the depression were a kettle hole, the validity of BARTLETT'S argument must still depend upon three further assumptions, all of which seem to me open to question: (1) the *Chamaecyparis* stumps occur in place from the bottom to the top of the deposit; (2) coastal subsidence is the only theory competent to explain such a succession of stumps in place; (3) the lower as well as the uppermost layers of the deposit are of recent date (i.e., formed within the last 2000 or 3000 years). Stumps certainly occur in place near the surface of the bog, and extensive soundings verified the abundance of wood found by BARTLETT in depth. But all of the cores which I was able to bring up by numerous tests showed the grain of the wood transverse to the core, indicating that I had encountered only trunks, branches, or roots lying horizontally. Of course, the chances of encountering the end of an upright stump are not great, but the fact that a day's almost continuous sounding failed to discover an undoubted stump in depth shows how difficult it must be to prove that the bog consists largely of stumps *in situ*. BARTLETT presents no evidence of the existence of such stumps in depth, aside from the fact that he encountered buried wood. In a number of cases I determined the form of the buried wood by abundant closely spaced soundings, and invariably found greatly elongated pieces, evidently logs or branches.

Even if stumps occur in place throughout the deposit, they cannot be cited as incontrovertible evidence of subsidence until we make sure that nature can in no other manner produce such a succession of stumps in place. It has occurred to me that floating bogs bearing trees might sink as new accumulations of material in place would be carried downward to the bottoms of ponds or lakes. Several botanical friends to whom I have appealed tell me that buried stumps might well be produced in this manner. PENHALLOW[19] describes a bog which, according to his interpretation, has had such a history. Surely then we are justified in doubting the assumption that stumps in place deep down in a kettle hole bog are conclusive proof of a change in the relative level of land and sea.

But if we granted that the phenomena cited by BARTLETT could be accepted as a proof of coastal subsidence, we must still ask for some satisfactory evidence of the age of the lower part of the deposit before we can accept it as a proof of recent subsidence. The upper part of the deposit may well be of recent date, and yet not be the result of coastal subsidence. If any part of the deposit proves subsidence it is the lower part, which cannot have been affected by changes in tidal levels. But are we sure that this lower part is of recent date? Surely those familiar with the antiquity of some of the peat bogs of Europe, in which wood and other substances are still well preserved, will hesitate to affirm that the lower part of a given peat bog must be of recent date as here defined.

When critically examined, neither the botanical nor other evidence of recent coastal subsidence seems to me conclusive. On the other hand, the physiographic evidence, so far as I have been able to analyze it, indicates a long period of coastal stability. The evidence in favor of stability I have already briefly outlined elsewhere, and I will present a more detailed account of it in a forthcoming report on the Shaler Memorial investigation of shore line changes along the Atlantic coast.

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[19] PENHALLOW, D. P., A contribution to our knowledge of the origin and development of certain marsh lands on the coast of New England. Roy. Soc. Canada, Proc. and Trans. III. 1^4:33–34. 1907.